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(54) **MULTIPLE STAGED COMPRESSOR WITH
LAST STAGE AIRFOIL COOLING**

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(52) **U.S. Cl.**
USPC **415/115**; 415/1

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(58) **Field of Classification Search**
USPC 415/1, 115
See application file for complete search history.

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(56) **References Cited**

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(*) Notice: Subject to any disclaimer, the term of this
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U.S.C. 154(b) by 66 days.

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Primary Examiner — David S Blum

(21) Appl. No.: **13/946,003**

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(57) **ABSTRACT**

Related U.S. Application Data

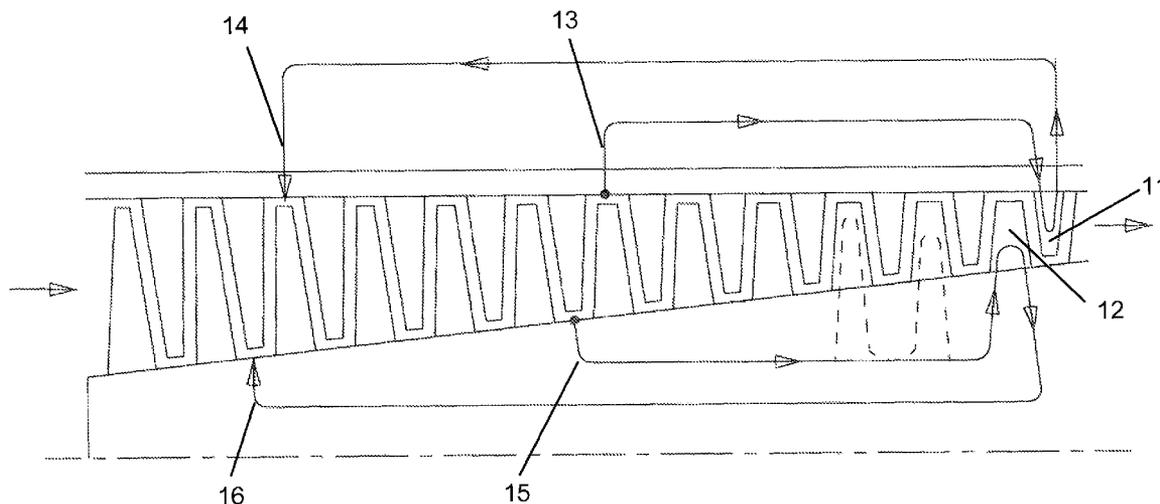
(63) Continuation-in-part of application No. 13/904,629,
filed on May 29, 2013, and a continuation-in-part of
application No. 13/526,601, filed on Jun. 19, 2012,
now Pat. No. 8,475,112, and a continuation-in-part of
application No. 12/268,340, filed on Nov. 10, 2008,
now Pat. No. 8,240,975.

A high compression ratio compressor having multiple stages
of airfoils to produce the high pressure ratios, where the last
stage airfoils are cooled by passing cooling air through the
airfoils without discharging film cooling air. A portion of the
compressed air from the discharge of the compressor is bled
off and passed through a heat exchanger to preheat a fuel and
to cool the compressed air. The cooled compressed air is then
passed through the last stage airfoil of the compressor to
provide cooling. The cooling air is then reintroduced back
into the compressor at an earlier stage or passed through an
airfoil in the turbine to provide cooling.

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29, 2007.

(51) **Int. Cl.**
F01D 5/14 (2006.01)
F03B 11/00 (2006.01)

11 Claims, 6 Drawing Sheets



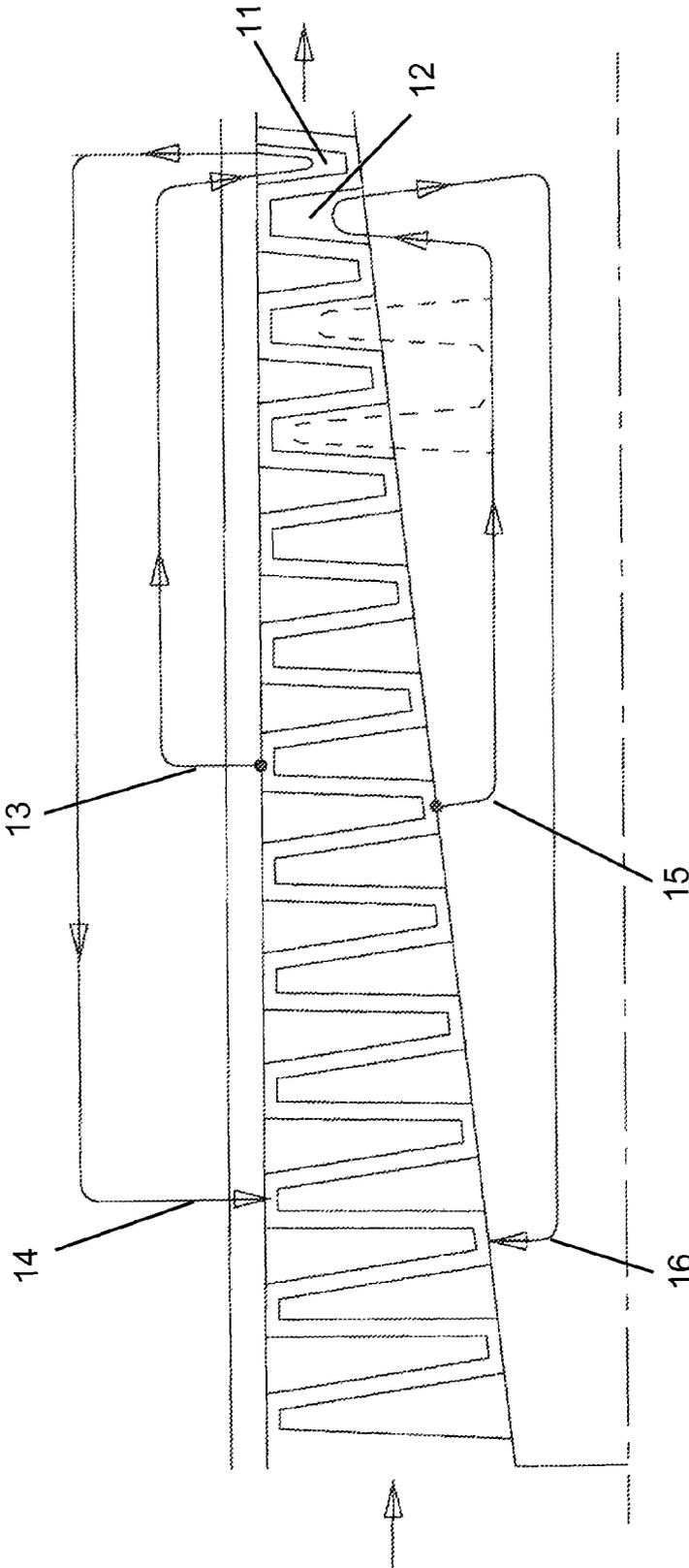


FIG 1

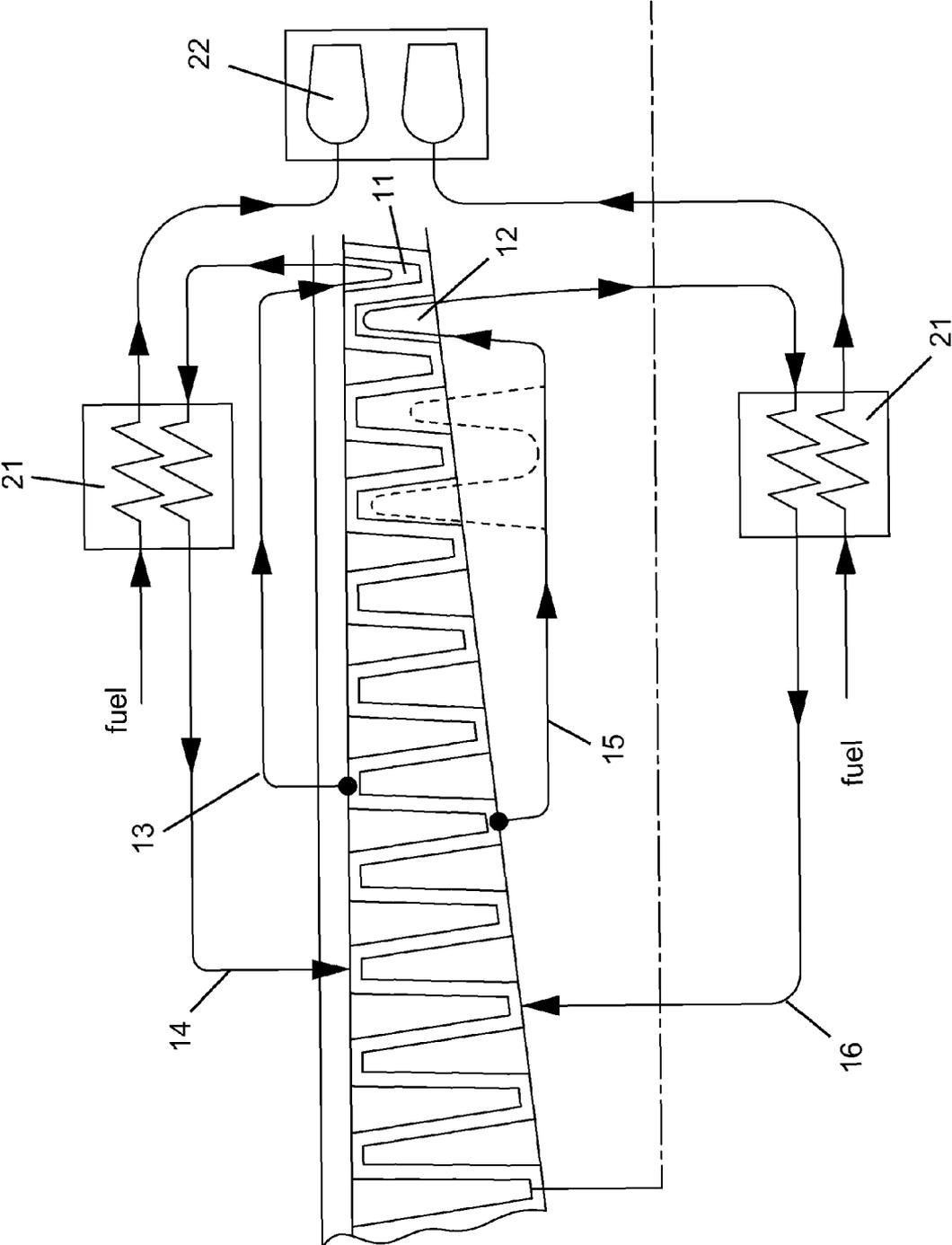


FIG 3

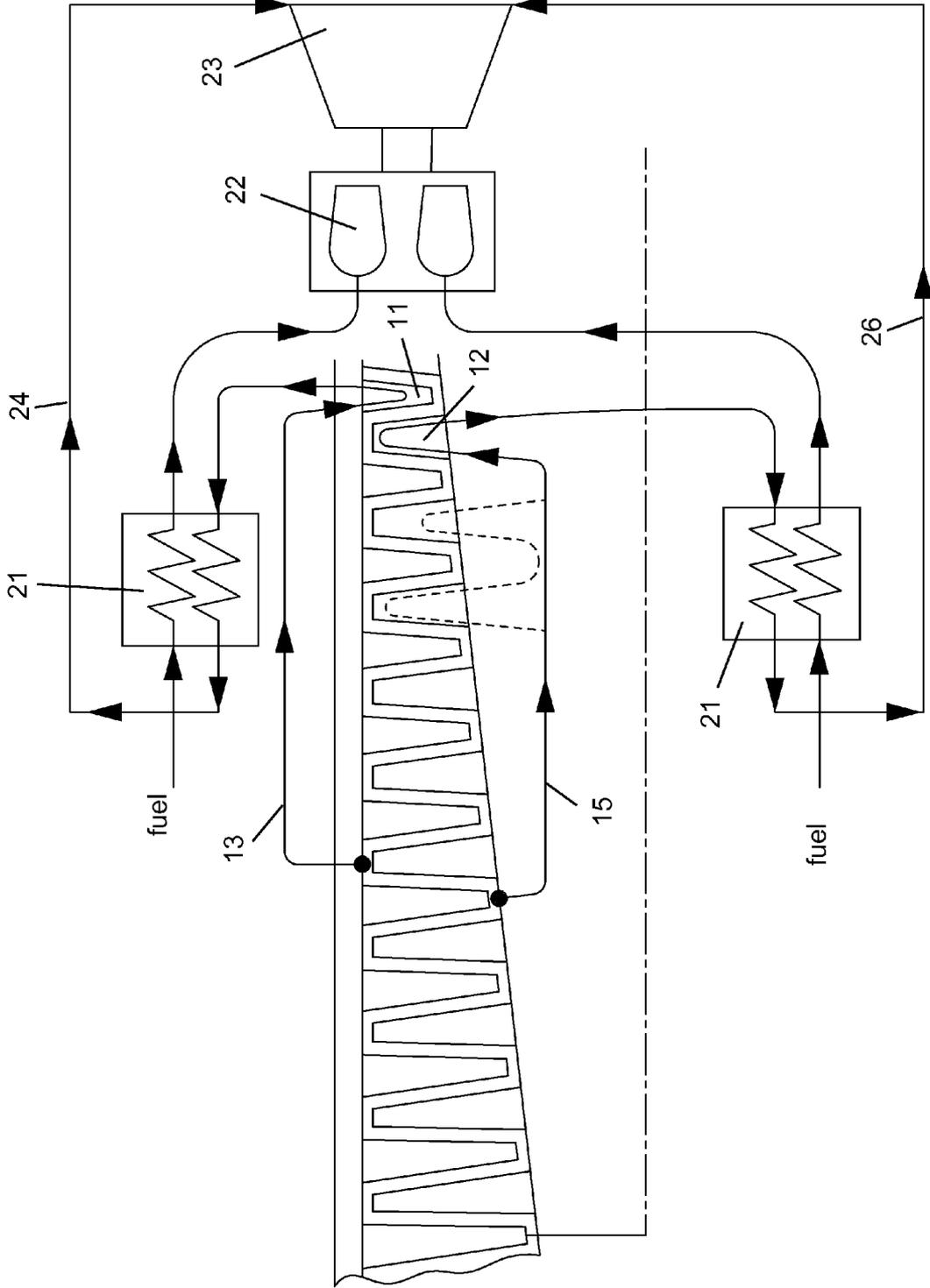


FIG 4

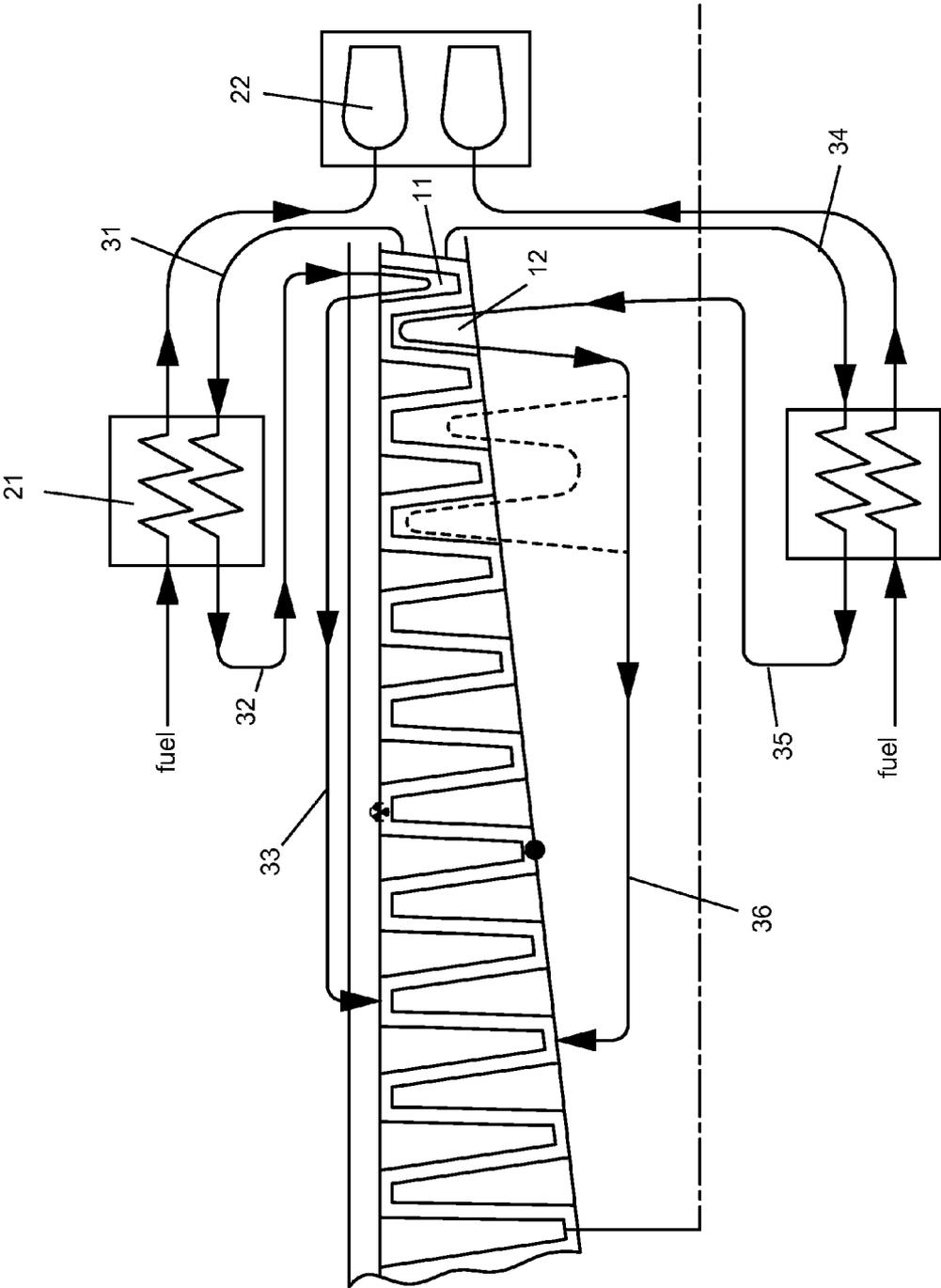


FIG 5

21

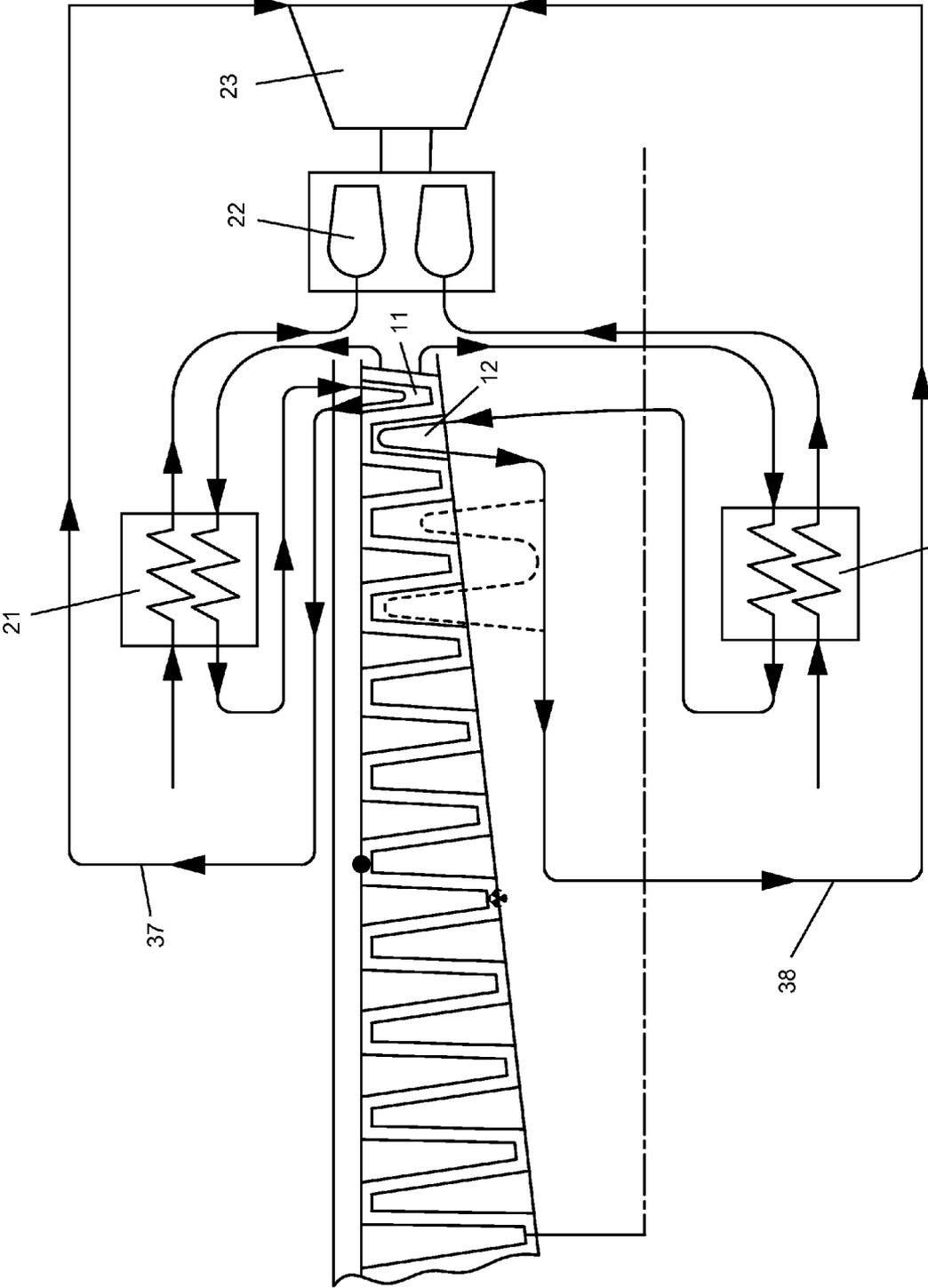


FIG 6 21

**MULTIPLE STAGED COMPRESSOR WITH
LAST STAGE AIRFOIL COOLING****CROSS-REFERENCE TO RELATED
APPLICATIONS**

This application is a CONTINUATION-IN-PART of U.S. patent application Ser. No. 13/904,629 filed on May 29, 2013 and entitled MULTIPLE STAGED COMPRESSOR WITH LAST STAGE AIRFOIL COOLING; which is a CONTINUATION-IN-PART of U.S. patent application Ser. No. 13/526,601, now U.S. Pat. No. 8,475,112, filed on Jun. 19, 2012 and entitled MULTIPLE STAGED COMPRESSOR WITH LAST STAGE AIRFOIL COOLING; which is a CONTINUATION-IN-PART of U.S. patent application Ser. No. 12/268,340, now U.S. Pat. No. 8,240,975, filed on Nov. 10, 2008 and entitled MULTIPLE STAGED COMPRESSOR WITH LAST STAGE AIRFOIL COOLING; which claims the benefit to U.S. Provisional Application 61/004,738 filed on Nov. 29, 2007.

GOVERNMENT LICENSE RIGHTS

None.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

The present invention relates to gas turbine engines, and more specifically to a high pressure ratio compressor with last stage airfoil cooling used in a gas turbine engine.

2. Description of the Related Art Including Information Disclosed Under 37 CFR 1.97 and 1.98

A gas turbine engine, such as an aero engine used to power an aircraft or an industrial gas turbine engine used to produce electric power, is a very efficient power plant. The compressed air from a compressor is passed into a combustor where the air is burned with a fuel to produce a hot gas flow, the hot gas flow is then passed through a turbine to drive the rotor shaft connected to the compressor and, in the case of an aero engine produce thrust and/or drive the fan, or in the case of the IGT drive an electric generator to produce the electric power. In both cases, the efficiency of the engine can be increased by passing a higher temperature gas into the turbine.

Modern gas turbine engines have multiple stages in the compressor in order to produce the very high pressure ratios between the outlet of the compressor and the inlet. For example, the Pratt & Whitney F100 aero engine that is used to power the military F15 and F16 fighter aircraft includes 13 stages in the compressor and produces a pressure ratio of 30 to 1 (the outlet pressure is 30 times the inlet pressure). A higher pressure ratio will allow for higher efficiencies for the engine. With the recent improvements in compressor design, a higher number of stages can be used to produce an even higher pressure ratio. Future aero engines are anticipated to have compressor ratios in the 50s.

However, as the air through the compressor is compressed, the temperature of the compressed air also increases. A multiple stage compressor will generally add 90 degrees F. to the compressed air for each stage. As the number of stages in the compressor grows, the compressor outlet air becomes higher to the point where the last stage airfoils (stator vanes and compressor blades) become so hot that the airfoils can be damaged from the high thermal load. Thus, there is a need in the prior art for a multiple stage compressor with a very high

pressure ratio to have cooling of the last stage airfoils in the compressor in order to withstand the higher temperatures.

BRIEF SUMMARY OF THE INVENTION

A compressor in a gas turbine engine in which the compression ratio is so high that the last stage rotor blades and stator vanes require cooling to prevent overheating of these airfoils due to the higher air temperature resulting from the increased compression ratio produced by the engine. The last stage blades and vanes include internal cooling air passages to produce cooling through convection and impingement. The compressed air used for cooling these airfoils is bled off from an upstream stage of the compressor, passed through the airfoils for cooling, and then reintroduced into the compressor at an upper stage from where the bleed off air was first extracted.

Because the air pressure used for the cooling of the last stage airfoils is less than the external air flow pressure around these cooled air foils, the cooled air foils cannot include discharging film cooling air for cooling the exterior surface because of the differential pressure. The cooled airfoils are thus cooled by a closed system and the spent cooling air reintroduced into the compressor at a location upstream from the bleed off location.

In a second embodiment of the present invention, heat pipes located in the last stage or later stages airfoils are used to draw heat away from the airfoils, and the cooling air passes through heat exchanges associated with the heat pipes to remove heat and cool the airfoils.

In another embodiment, the cooling air used to cool the last stage airfoils can be used to preheat a fuel used in a combustor of the engine, where the fuel then cools the cooling air prior to being reintroduced into the compressor, preferably at a stage having a temperature close to the temperature of the cooled cooling air.

In still another embodiment, the cooling air of the last stage airfoils is cooled in a heat exchanger by passing fuel through, where the cooled cooling air is then passed through a last or near-last stage of a turbine to cool the airfoils.

In another embodiment, compressed air from the last stage of the compressor is first passed through a heat exchanger that uses fuel as the heat exchange fluid to preheat the fuel and cool the compressed air, where the cooled compressed air is then passed through the last stage vanes and blades of the compressor to provide cooling for these airfoils. The cooling air is then either reintroduced back into the compressor at an earlier stage or passed through a latter stage airfoil in the turbine to provide cooling of these airfoils.

**BRIEF DESCRIPTION OF THE SEVERAL
VIEWS OF THE DRAWINGS**

FIG. 1 shows a cross section view of a first embodiment of the multiple stage compressor of the present invention.

FIG. 2 shows a cross section view of a second embodiment of the multiple stage compressor of the present invention having heat pipes.

FIG. 3 shows a cross section view of a third embodiment of the multiple stage compressor of the present invention with a heat exchanger to use a fuel to cool down the cooling air from the last stage airfoils, where the fuel is then passed into a combustor and the cooled cooling air is reintroduced into the compressor.

FIG. 4 shows a cross section view of a fourth embodiment of the multiple stage compressor of the present invention with a heat exchanger to use a fuel to cool down the cooling air

from the last stage airfoils, where the fuel is then passed into a combustor and the cooled cooling air is used to cool airfoils in a last stage of a turbine.

FIG. 5 shows cross section view of a fifth embodiment of the multiple stage compressor of the present invention where compressed air from the last stage of the compressor is passed through a heat exchanger to preheat a fuel with the cooled compressed air then passing through the last stage airfoils of the compressor to provide cooling, and where the cooling air is then reintroduced back into the compressor at an earlier stage.

FIG. 6 shows cross section view of a sixth embodiment of the multiple stage compressor of the present invention where compressed air from the last stage of the compressor is passed through a heat exchanger to preheat a fuel with the cooled compressed air then passing through the last stage airfoils of the compressor to provide cooling, and where the cooling air is then passed through the last stage airfoils of the turbine to provide cooling.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is a multiple stage compressor that produces a very high pressure ratio such that cooling of the last stage or stages of the compressor air required. The compressor is intended to be used in a gas turbine engine such as an aero engine or an IGT engine. However, the present invention could be used in any turbomachine in which a multiple stage compressor is used that produces the high pressure ratio in which cooling of the last stage airfoils is required to prevent thermal damage.

FIG. 1 shows a cross section of the compressor of the present invention in which a number of stages are present with each stage having a stator or guide vane located upstream from an associated rotor blade. In a typical multiple stage compressor of an aero engine, the outer diameter of the compressor is about at a constant radial diameter while the inner diameter is conical shaped with a decreasing airfoil spanwise height in the downstream direction. The inlet air to the compressor is at atmospheric pressure. The compressor progressively compresses the air as the compressed air passes through the multiple stages. As the air is compressed, the temperature of the compressed air increases. A typical compressor will increase the compressed air temperature about 90 degrees F. in each stage. In the last stages, the compressed air can be at such a high temperature that the airfoils can be damaged from the high temperature. The material properties of these airfoils are such that the high temperature compressed air passing through these airfoils exceed the safe temperature level for the materials.

In the present invention is FIG. 1, the last stage vanes 12 and blades 11 include closed loop cooling air passages to pass cooling air through the airfoils without discharging the cooling air into the high temperature compressed air stream through the compressor. The internal airfoil cooling passages can be any type of prior art closed loop cooling passage circuit that makes use of well known convection cooling and impingement cooling of airfoils. Compressed cooling air from a middle stage 15 of the compressor is bled off and passed through a cooling air passage in the rotor shaft assembly and into the inlet of the internal cooling air passage of the rotor blade. The cooling air passes through the rotor blade cooling passage and then flows through a return air passage also in the rotor shaft to be discharged into the compressor at a stage 16 upstream from the bled off stage. This is due to the loss of pressure in the cooling air from passing through the cooling passages in the rotor shaft and the rotor blade.

To cool the last stage stator vane 11, cooling air is also bled off from the compressor at a middle stage 13 and directed through a cooling air passage and into the internal cooling air passage formed within the stator vane. The cooling air passes through the vane cooling passage, and is then directed through a return air cooling air passage and into the compressor at a stage 14 upstream from the bled off location. This is also due to the loss of pressure in the cooling air from passing through the cooling supply passages in the casing and the stator vane. The bleed off air used for cooling of the last stage airfoils is from the lowest stage that would produce enough pressure to pass through the cooling circuit for the airfoils while still allowing for the spent cooling air to be discharged into an upstream stage of the compressor. The further down the compressor stages that the cooling air is bled off from, the higher the temperature of the cooling air used to pass through the airfoils for cooling.

Bleeding off the compressed air used for the cooling and then re-supplying the cooling air back into the compressor minimizes the loss in the compressor. The heat picked up from the cooling air passing through the cooling passages within the airfoils is passed back into the compressor mainstream air. The only significant losses are due to the pressure loss from the cooling air passing through the cooling passages from the bleed off location to the re-supply location.

In other embodiments, other stages of the blades and vanes in the compressor can also be cooled by passing bleed off cooling air through the internal cooling passages and then re-supplying the cooling air to the compressor. The number of stages in the compressor that require cooling would depend upon the compressed air temperature passing through those stages. Also, the stage at which the cooling air is bled off will depend upon the required pressure for the cooling air that is needed to pass through the cooling air passages and be discharged back into the compressor. The re-supply locations will depend upon the pressure difference between the main stream compressed air and the re-supply cooling air. The re-supply cooling air must be at a higher pressure than the mainstream compressor air or a backflow will occur. Since the airfoil internal cooling passage is a closed loop passage (no cooling air is discharged from the airfoil out into the mainstream compressor air flow), the pressure of the cooling air can be lower than the pressure of the main stream compressed air passing through that airfoil.

Also, in another embodiment, the cooling air can be discharged into the turbine section to provide cooling for turbine airfoils such as rotor blades and stator vanes and then discharged into the hot gas flow passing through the turbine if the pressure differential is high enough to prevent backflow into the turbine airfoils.

In another embodiment, the cooling air from the compressor airfoils can be passed through a turbocharger to increase the pressure of the cooling air, and then passed into the combustor to be burned with the fuel. With this embodiment, the heated cooling air is burned with the fuel to produce the hot gas flow that is passed through the turbine to drive the rotor shaft.

FIG. 2 shows an embodiment of the present invention in which the cooling air does not pass through the last stage airfoils. In the closed loop cooling circuit of FIG. 1, if an airfoil was to crack then the hot compressed air from the compressor can leak into the internal cooling passages of the last stage airfoils. To prevent this, the FIG. 2 embodiment uses heat pipes 21 and 23 that extend into the last stage airfoils 11 and 12 to draw heat away and into heat exchangers 22 and 24. The compressed air bled off from the compressor at 13 and 15 is passed through the heat exchangers 22 and 24 to draw heat

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away from the heat pipes **21** and **23** and thus the last stage airfoils **11** and **12** to cool the airfoils. With the use of heat pipes in the last stage airfoils **11** and **12**, no high temperature compressed air can leak into the cooling air passages.

In the FIG. **3** embodiment, a heat exchanger **21** is used to cool the cooling air from the last stage or near-to last stage airfoils prior to the cooled cooling air being reintroduced into the compressor. The fuel is thus preheated prior to passing into a combustor of the engine to be burned with compressed air from the compressor to produce a hot gas stream for the turbine. The cooling air bled off from one stage of the compressor in lines **13** and **15** is used to cool the stator vanes **12** and rotor blades **12**, and then passed through the heat exchanger **21** and reintroduced into a lower pressure stage of the compressor through lines **14** and **16**. It is preferable that the cooled cooling air be reintroduced into the stage of the compressor having close to the temperature of the cooled cooling air.

In the FIG. **4** embodiment, the heat exchanger **21** is used to cool the cooling air from the last stage airfoils **11** and **12** and preheat the fuel prior to passing into the combustor **22**, but the cooled cooling air is not reintroduced into the compressor but is used to provide cooling for last stage airfoils in the turbine **23** of the engine. Cooled cooling air in lines **24** and **26** is passed into the stator vanes and rotor blades of the turbine for cooling. The preheated fuel is passed into the combustor to produce the hot gas stream for the turbine **23**.

FIG. **5** shows an embodiment of the present invention in which some of the compressed air from the last stage of the compressor is passed through the heat exchanger **21** to be cooled using fuel as the heat exchanger fluid that preheats the fuel prior to introduction into the combustor **22**. The cooled compressed air is then passed through the last stage stator vanes **11** through line **32** and through the last stage rotor blades **12** through line **35** to provide cooling for the last stage airfoils on the compressor. The cooling air then flows through lines **33** and **36** to be reintroduced back into the compressor at an earlier stage having lower pressure. The preheated fuel is burned with the remaining compressed air discharged from the compressor last stage airfoils. The dashed lines in FIG. **5** represent other airfoils that can also be cooled using compressed air bled off from and cooled using the fuel in order to limit the metal temperature of these airfoils within the compressor.

FIG. **6** shows an embodiment of the present invention similar to FIG. **5** except that the cooling air from the airfoils in the compressor is not reintroduced back into the compressor but passed through airfoils within the turbine **23** that require cooling. The cooling air from the compressor will have a lower pressure than at the discharge end of the compressor and can be used to provide cooling for the last stage airfoils within the turbine or other stage airfoils. The cooling air for the turbine airfoils can also be passed into the hot gas stream through film holes or exit holes formed in the airfoils.

We claim the following:

1. A gas turbine engine comprising:

a multiple stage compressor with stages of stator vanes and rotor blades;

a combustor;

a turbine;

a heat exchanger;

a last stage of airfoils in the compressor having an internal cooling air circuit to provide cooling for the airfoil;

a cooling air supply passage to supply cooling air to a cooling air inlet of the last stage airfoil;

the cooling air supply passage connected to an outlet of the compressor;

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a cooling air discharge passage to discharge spent cooling air from a cooling air outlet of the last stage airfoil; the cooling air discharge passage passing through the heat exchanger;

a fuel passing through the heat exchanger to cool the cooling air discharged from the last stage airfoil; and, passing the preheated fuel into the combustor.

2. The gas turbine engine of claim **1**, and further comprising:

the cooling air discharge passage connected to the heat exchanger is connected to the compressor to reintroduce the cooling air from the heat exchanger back into the compressor.

3. The gas turbine engine of claim **2**, and further comprising:

the cooling air discharge passage is connected to a stage of the compressor having a temperature close to the temperature of the cooling air cooled in the heat exchanger.

4. The gas turbine engine of claim **1**, and further comprising:

the last stage airfoil of the compressor is a stator vane and a rotor blade; and,

the cooling air from the last stage stator vane and rotor blade is passed through the heat exchanger to cool the cooling air.

5. The gas turbine engine of claim **1**, and further comprising:

the cooling air discharge passage from the heat exchanger passes through the turbine to provide cooling for a last stage airfoil in the turbine.

6. The gas turbine engine of claim **1**, and further comprising:

the multiple stage compressor is an axial flow compressor.

7. A process for operating a gas turbine engine, the gas turbine engine having a multiple stage compressor, a combustor and a turbine, the process comprising the steps of:

compressing air in the multiple stage compressor from a first stage to a last stage;

bleeding off a portion of compressed air from the compressor at a discharge end of the compressor;

passing the bleed off air from the compressor through a heat exchanger to preheat a fuel and to cool the bleed off compressed air;

passing the cooled bleed off air through the last stage airfoil of the compressor to cool the last stage airfoil; and,

passing the preheated fuel into the combustor to be burned with compressed air from the compressor and produce a hot gas stream for the turbine.

8. The process for operating a gas turbine engine of claim **7**, and further comprising the step of:

reintroducing the cooling air from the last stage airfoil back into the compressor.

9. The process for operating a gas turbine engine of claim **8**, and further comprising the step of:

reintroducing the cooling air from the last stage airfoil into compressor at a stage having a temperature close to the temperature of the cooling air.

10. The process for operating a gas turbine engine of claim **7**, and further comprising the step of:

passing the cooling air from the last stage airfoil through the turbine to cool a last stage airfoil of the turbine.

11. The process for operating a gas turbine engine of claim **7**, and further comprising the step of:

compressing the compressed air in the compressor with an axial flow compressor.